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AUTHOR	Kusmierek, Kristin N.; Piontek, Mary
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ABSTRACT

Multidisciplinary education attempts to produce individuals with new capacities to address the problems of an increasingly interconnected world. Although these programs are often exciting, descriptions of optimal design and measures of success are few. Emerging evaluation results from one multidisciplinary graduate training program provide insights into the development of differently trained scientists. The program aims to train doctoral students from a range of science disciplines to conduct research on environmental questions that lie at the interface of biospheric and atmospheric sciences. Data were collected from faculty and students who participated in the program's first 2 years. The first cohort contained six students for 2000-2001 and five for 2001-2002, and the second cohort, which had finished only its first year, contained four students in 2001-2002. Evaluation findings have informed program modifications that better facilitate students' integration of new learning. Additional findings suggest how students describe their progress—characterized by content acquisition, awareness of disciplinary connections, and interaction across disciplinary communities—toward multidisciplinarity. (Contains 1 table and 25 references.) (Author/SLD)

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Content, Consciousness, and Colleagues: Emerging Themes from a Program Evaluation of Graduate Student Progress Toward Multidisciplinary Science

Kristin N. Kusmierek
BART IGERT Program Evaluator/Doctoral Student
Center for the Study of Higher and Postsecondary Education
University of Michigan School of Education
611 East University, 2117 SEB
Ann Arbor, MI 48109-1259
(734) 764-9472
kriskus@umich.edu

Mary Piontek
Evaluation Researcher
Center for Research on Learning and Teaching
University of Michigan School of Education
611 East University, 3325 SEB
Ann Arbor, MI 48109-1259
(734) 615-4617
mpiontek@umich.edu

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Communications may be directed to Kristin Kusmierek,
3-2810 Bloor Street West, Toronto, ON M8X 1A7, Canada
(416) 236-2833, kriskus@umich.edu

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Content, Consciousness, and Colleagues: Emerging Themes from a Program Evaluation of Graduate Student Progress Toward Multidisciplinary Science

Abstract

Multidisciplinary education attempts to produce individuals with new capacities to address the problems of an increasingly interconnected world. Although these programs are often exciting, descriptions of optimal design and measures of success are few. Emerging evaluation results from one multidisciplinary graduate training program provide insights into the development of differently trained scientists. Evaluation findings have informed program modifications that better facilitate students' integration of new learning. Additional findings suggest how students describe their progress--characterized by content acquisition, awareness of disciplinary connections, and interaction across disciplinary communities--toward multidisciplinarity.

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Introduction

Not only educators, but professionals throughout industry and commerce, have recognized the need for citizens who can address the demands of a complex and increasingly technological age (Klein & Newell, 1997; Stark & Lattuca, 1997). Graduate education has been called to produce graduates who can work in the interstices of the well-honed paths and respond to new intellectual and technological developments (COSEPUP, 1995; Moffat, 1995). Some scholars, however, have predicted difficulties in working outside traditional expectations and disciplines, the organizing principles which have worn ruts in educational and research efforts, leaving distinct patterns to govern curriculum, scholarly interaction, and research techniques and methodologies (Lattuca & Stark, 1994). Nonetheless, the emergence of innovative graduate education and training programs is one attempt to produce researchers with new capabilities that cross and combine disciplines. Now we must create the educational infrastructure to identify, evaluate, and sustain the productive advancements that these programs offer.

This study, at core, asks the primary questions of the program evaluation interested in student development and educational outcomes and processes: "How do graduate students, at least in this program, learn to become multidisciplinary scientists?" The program assumes that several factors, including research and professional skills, contribute to young scientists' success, so practical sub-questions include "How, and to what extent, do students learn to conduct research at the interface of multiple disciplines?" and "How, and to what extent, do they learn to operate in professional communities that draw upon multiple disciplines?" While these are questions about process, perhaps the ultimate question of the program, the evaluation, and the entire endeavor is: "What does a multidisciplinary scientist look like?"

Motivating Literature

Although undergraduate education has long endured scrutiny and reform, graduate education has more recently encountered greater attention. With some frequency throughout its history, scholars and practitioners have examined graduate education's structure and basic outcomes, considering enrollments, retention, time-to-degree, funding effects and the disciplinary differences among these (Bowen & Rudenstine, 1992; Baird, 1993; Nerad, June, and Miller, 1997). Perhaps influenced by national educational trends toward accountability, the last decade has infused issues of quality and a call for increased assessment of graduate education (Haworth, 1996; Baird, 1996). This call has been acknowledged by various studies within specific departments, programs, and disciplines (Hanson, 1990; Regan-Smith, 1994), but this work has been seldom extended into cross-disciplinary or cross-institutional efforts (Stark, Lowther, & Hagerty, 1986; Golde & Gallagher, 1999).

Much more recently, the entire system of graduate education has drawn criticism, yielding broader national reports and studies (COSEPUP, 1995; Golde & Dore, 2001). It has been acknowledged that society, students, and technology have changed; thus, graduate education must be reconsidered within this new framework. While some scholars have focused on the needs of new types of students (Pruitt-Logan & Isaac, 1995), others have highlighted the need to match the curriculum and outcomes of graduate education with the needs of the a new generation of teaching faculty (Duderstadt, 2000) and a new workforce (COSEPUP, 1995). For example, expanding industry warrants the attention of doctoral graduates, historically trained for academic careers under the original purposes of doctoral education but now desiring to retool themselves to pursue other careers. The role and purpose of graduate education in all its facets is being reconsidered in theory and revamped in practice.

In response to these trends, innovative graduate education programs and initiatives have begun to appear. Among these are interdisciplinary programs such as those supported by the National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT) program, which strives not only to diversify graduate student populations in science and engineering, but also to produce graduate students with multidisciplinary backgrounds and the technical, professional, and personal skills to pursue productive careers in a dynamic future. Although numerous scholars have pursued questions of interdisciplinarity (OECD, 1972; Klein, 1990; Klein & Newell, 1997; Lattuca, 2001), many of these have emphasized theory or faculty conceptions of interdisciplinary endeavors. Programs such as IGERT are new to the scene and strive for new educational experiences for graduate students, unlike those that have received the attention of the past. As such, studies of these programs, evaluations of their innovations, and scholarly considerations of their educational processes and outcomes are crucial.

Evaluation Design

The data and analyses presented here are part of a multi-year, formative program evaluation of a federally funded, multidisciplinary graduate education and research training program for students in the sciences. The program aims to train doctoral students from a range of science disciplines to conduct research on environmental questions that lie at the interface of biospheric and atmospheric sciences, two domains of individual concern that interact and contribute prominently to the national research agenda. Global climate change, for example, is one such multidisciplinary topic affected by the interactions of plants, air, water, soil, and humans, among other things.

The Context—The Program Under Review

The educational goals of the program are multiple, but the primary purpose is to provide doctoral students with the training necessary to pursue research at the interface of two disciplinary domains. Additional goals lie in three primary areas: 1.) students' acquisition of content and technical knowledge crucial to both fields, 2.) the creation of a multidisciplinary community of scholars, and 3.) the enhancement of students' professional skills.

Although multi-institutional in its university, student, and faculty participation, the program relies heavily on immersion in a field research setting at the biological station of a large Midwestern research university. In addition to two years of fellowship support for graduate study within traditional departments at their home institutions, participating students spend two summers at the biological station. The first summer offers a series of intensive workshops on topics and techniques fundamental to the two fields. The students also begin their proposed field research with the assistance of two mentors, one from each discipline. The second summer emphasizes research almost completely. Additional instructional activities, such as research presentations and reading groups, occur throughout the two years.

Sample

Data presented here were collected from faculty and students who participated in the program's first two years (2000-2002). Given the program's

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two-year cycle, this means that Cohort 1 (6 students for 2000-2001 and 5 in 2001-2002) was tracked to near completion, and Cohort 2 completed its first year (4 students in 2001-2002). Because the program has few restrictions other then Ph.D. student status at a participating university, the students themselves had few commonalities: Ages ranged from early twenties to early forties, student status ranged from newly admitted graduate students to doctoral candidates, and prior educational experience came from a wide array of institution types. Students were studying various science disciplines at their home institutions, but most were affiliated with fields related to biology, chemistry, or earth sciences.

Participating faculty for the program have been defined for program evaluation purposes as all faculty who serve as the mentors, instructional faculty, administrative committee members, and initial proposal supporters. These individuals number roughly thirty, changing somewhat annually, and serve at their home institutions in an array of science fields.

Evaluation Methods and Analysis

Formative program evaluation, proposed with the original program, began in August 2000 during the program's first summer. Designed and implemented by an educational researcher, the evaluation is largely exploratory, given the innovative nature of the program and the lack of empirical research regarding the acquisition of multidisciplinary educational outcomes. Three basic goals drive the evaluation:

1.) to understand the program's impact on the development of participating students,
2.) to understand the program's impact on participating faculty, and

3.) to create an infrastructure through which to understand the program's effects on disciplinary boundaries.

Throughout, data, largely qualitative, have been collected primarily through observation and survey research techniques, emphasizing semi-structured interviews and written surveys, distributed either on paper or via email attachment. Data have also been gathered from program records and artifacts. (See Table 1.) The participating faculty (n = 30) were surveyed in the Year 2 (2001) of the program, yielding a 43% response rate.

Treatment of the data

Hand-written interview notes, open-ended survey responses, and other qualitative data were coded and analyzed, using an iterative, constant comparative method (Merriam, 1998; Creswell, 1998). Inductive analysis revealed emerging themes, clustering related items. The resulting categories served to generate further explorations and analyses of the data.

Findings

Findings of the program evaluation remain preliminary and ongoing, but three primary categories have been: 1.) issues of program design, 2.) issues related to defining multidisciplinarity and 3.) issues of students' achievement of multidisciplinary outcomes.

Program Design Issues

Even if constructed with the best intentions and insight, any new educational program requires evaluation and adjustment once implemented. The program evaluation uncovered issues that figured prominently in the minds of program personnel and student participants early in the program's implementation.

Table 1: Program Design—Evaluation Activities for a 2-Year Program Cycle

SCHEDULE	ACTIVITY	PARTICIPANTS
Entry/Beginning Summer 1	One-on-one interviews with survey component on multidisciplinarity	First-year students
	Subject matter surveys	First-year students
Ongoing during Summer 1	Workshop evaluations	All student participants
Mid-Summer 2	Informal feedback solicitation	All students
End of Summer 1	One-on-one interviews with survey component on multidisciplinarity	First-year students
	One-on-one interviews	Program personnel
	Subject matter surveys	First-year students
Beginning Summer 2	Academic Year Experience Survey	Second-year students
Mid-Summer 2	Informal feedback solicitation	All students
End of Summer 2	One-on-one interviews with survey component on multidisciplinarity	Second-year students
	One-on-one interviews	Program personnel
Exit/Program completion	One-on-one interviews with survey component	All students
	One-on-one interviews	Faculty mentors

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Although some of these issues were straightforward and led easily to adjustment, some reveal interesting lessons or highlight curious paths for further investigation. I discuss the most prominent—that of the program structure's effect of student motivation—below.

Student motivation and program calendar. During the first summer of the program, student motivation emerged as a prominent issue in the minds of all participants and personnel--although for conflicting reasons. Program personnel expressed extreme concern about the lack of student motivation, indicated largely by students' lack of research progress and poor morale. On the other hand, students appeared to the program evaluator as genuinely excited about the program, freely discussing multiple reasons for their application and participation, many of which related to the unique multidisciplinary emphasis of the program and the students' other personal goals:

- Appeal of the multidisciplinary nature of the program and its goals
- Opportunities to build science skills generally
- Opportunities to interact with important people in science
- Encouragement of academic or research advisor
- Opportunity to extend appealing research
- Opportunity to defy over-specialization of the Ph.D.
- Enhanced marketability in terms of career pursuits
- Opportunities for shift in fields
- Financial support

The students did admit an increasingly poor morale, however, and attributed this to feeling overwhelmed and taxed by competing goals and time constraints. Although differences in prior experience may have contributed to students' varying abilities to integrate new knowledge or negotiate field research, almost all participating students in Cohort 1 described a similar experience in the first summer of the program.

An analysis of the logistics regarding the program's instructional components, in conjunction with student and personnel reports, revealed an interpretation for students' poor research progress and potentially explained students' reactions: that structural factors of the program may have hindered students' achievement and amplified students' natural frustrations with new learning.

Three categories of concern with the first year's program calendar emerged as pervasive:

- Pace/intensity—the number of activities and their extent/scope
- Scheduling—the arrangement of activities
- Interconnectedness—the degree to which activities were connected to each other

In short, both participating students and faculty found the calendar exhausting, but faculty appeared better able to cope with the ramifications of that. The pace was intense, the scheduling tight, and interconnections few. The calendar allowed students little time for reflection on new learning and program personnel little time to facilitate integration of new knowledge. During the nine-week summer program, workshops and formal activities filled all or part of eighteen days; the calendar was somewhat front-loaded so that the first half of the summer contained more workshops, leaving the second half of the summer more available for students' research efforts. Although some workshops also required preliminary reading or subsequent "homework," it is unclear how thoroughly this work was completed or reviewed by faculty. While both faculty and students perceived the workshops as valuable, the students felt that the time and energy devoted to the workshops competed with their research efforts.

Some students described how the idiosyncrasies of field research complicated things. For example, some students needed more time than others to set up their research before collecting data—making the front-loading of the workshops detrimental to early research tasks. Other students used instruments or data that were weather dependent (e.g., limiting research opportunities in rain, clouds, or wind), so weeks that coincidentally held workshops on sunny days and left a day or two free for research were only useful if they provided sufficient blocks of sunny and calm weather.

Although program personnel asserted that adequate time existed for both educational and research components of the program, the students' experience contradicted that. Although some differences existed in how much personal time was expected, the time and energy devoted to multifaceted and complex learning and research on the part of students was perhaps underestimated by all concerned. While the students were charged with absorbing and integrating new information about multiple fields, they were also required to advance their field research from set-up through data collection, sometimes independently or with minimal supervision. Both tasks placed students in new contexts with significant practical, intellectual, and psychological demands.

While students' personal and professional goals often reinforced their desire to learn about a new discipline, much of the new content could not be immediately applied in their research, so learning felt uncertain and tangential in the short-term. Conversely, both the program and the general structures of graduate education reinforced students' need to advance individual research, a similarly time and energy intensive commitment. The most objective goals of the program were associated with research productivity. The tensions that resulted from these factors left students short on time, somewhat overwhelmed by new knowledge, struggling with the field research that would prove their achievement, and frustrated with their lack of footing.

In order to attempt to improve the situation, the schedule for Year 2 was changed such that larger blocks of time were allowed earlier in the summer, alternating between time for research and workshops. Although the amount of new content remained constant, scheduling better allowed for both educational workshops and adequate research start-up. Although integration and the interconnectedness among activities was not directly amplified, the increased "breathing room" was perceived to address this concern. Where the program personnel saw a minor adjustments, the students expressed relief. Indeed, although program evaluation of this sort makes it difficult to define causality and cohort differences, Cohort 2 displayed very few of the signs of frustration, exhaustion, and poor morale described above and did appear to make greater gains in advancing research.

Defining Multidisciplinarity

While some scholars ruminate about the structure of disciplines, theories about how they evolve and govern knowledge and inquiry, and how they are defied by some scholars (see summaries by Klein, 1990, and Lattuca, 2001), others merely use the terms "disciplinary," "interdisciplinary,"

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"multidisciplinary," and others in an instrumental way. The program analyzed here assumed a collective understanding of the terms "multidisciplinary" and "interdisciplinary," generally viewed as used interchangeably. The program formally used "multidisciplinary" to describe its educational goals and structure, characterized by a synthetic view of environmental systems and broad exposure to relevant science fields; however, in the absence of an explicit working definition, the program evaluation explored participants' (both student and faculty) perceptions of the meaning and use of the term. Confirming initial suspicions, student and faculty responses revealed substantial variance in perceived meaning and use of "multidisciplinary" as well as the often similarly used "interdisciplinary."

Participants' responses revealed categories of features that are common to conceptions of multidisciplinary work—although participants discussing the same categories sometimes disagreed on the exact features that made an endeavor multidisciplinary. The categories emerged as:

- Number of disciplines involved in the endeavor
- Content of each discipline that is essential to endeavor
- Number of people involved in the endeavor
- Relationship of the multiple disciplines to each other
- Type of problem that is pursued
- Type of product that results

Number of disciplines involved. Most participants appear to agree easily that multidisciplinary work somehow involves more than one discipline. As one participating students simply stated, "Multidisciplinary work combines the perspectives of two or more formally defined disciplines."

Content essential to the endeavor. Participants' descriptions of multidisciplinary work noted disciplinary subject matter that can be borrowed from any one discipline and applied to a new task. These content items reflect the cultural commonalities of a community of scholars and the systems of belief and practice organized by disciplines:

- Concerns
- Data
- Expertise
- Ideas
- Knowledge
- Methods or methodologies
- Perspectives
- Theories
- Tools or techniques

Although numerous participants listed several of these items in their considerations of multidisciplinary work, no one named all of them or explicitly discussed which may be crucial or more significant than others. Their use appeared merely shorthand for the general content of a traditional discipline, now applied to a new type of entity—one that draws upon the subject matter of several previously distinct disciplines.

Number of people involved in the endeavor. Both students and faculty participants presented views about the number of people needed to approach a multidisciplinary task. Some stated that multidisciplinary work required collaboration, as did this student:

> I think multidisciplinary work involves understanding aspects of a problem and how they relate to each other from various 'standard'

> disciplines…I think it is truly hard for one person to understand all the different aspects, but hopefully a team of people can work together on one problem and provide that necessary insight that one person alone would not be able to provide.

On the other hand, another student took an opposing view, while juxtaposing ideas about multidisciplinary with interdisciplinary:

> Interdisciplinary seems to infer (sic) cooperation between two or more people, each trained in a different discipline, while multidisciplinary seems to infer (sic) one person employing several perspectives.

Despite the inconsistencies, these responses revealed a reoccurring concern about the abilities of the individual. Some tasks were perceived as beyond the capacity of the individual, requiring the researcher to draw upon a community of colleagues, presumably to investigate those complex questions that cross the boundaries of multiple disciplines, whatever term we use to denote that.

<u>Relationship of the multiple disciplines to each other.</u> Ideas about the structure of disciplines and their connections to each other emerged from participants' comments, usually in faculty's descriptions of the relationships implicit in multidisciplinary projects. Often, the disciplines comprising multidisciplinary work were seen as be distinct and unrelated to each other, perhaps implying a greater stretch for the researcher or team. The separateness was sometimes articulated as a product of traditional organizational structures. This faculty participant offered an example:

> Drawing from multiple (>=2) disciplines, which are often separated by departmental or organizational barriers, in a significant way. By 'drawing

> on' is meant using knowledge, methods and/or data from. Thus, a study of the biological mechanisms by which an air pollutant affects plants could be multidisciplinary, if the study included study of atmospheric conditions, but would not be multidisciplinary if only the biological mechanism were analyzed.

Other examples present the opposite view, that disciplines comprising multidisciplinary work are at least somewhat related, perhaps even as subfields within a single discipline. As one first-year student asserted, multidisciplinary work consists of "research or studies that span a variety of interrelated fields."

Responses also yield a third category of disciplinary relationships—that of a unique field of inquiry that is not neatly defined. Participating faculty describe multidisciplinary work as:

> Research that combines ideas and methods from a variety of sometimes distantly related fields to produce a new knowledge system.

> Multidisciplinary work requires knowledge, expertise, and/or techniques that do not fit neatly into one of the "traditional" disciplines. When someone describes their research, and you cannot immediately guess correctly what university department they are in or got their degree in, that would be a clue that their research is interdisciplinary/ multidisciplinary.

Such comments imply not only a consideration of disciplinary structure, but also disciplinary culture, and acknowledge the location of some work outside of the traditional domains—with results perhaps challenging the traditional domains.

Type of problem. Another common and related theme in participants' considerations is that multidisciplinary work was seen to address a complex research problem. Most often the problem being addressed was seen as pertinent to the concerns of multiple disciplines. Other respondents conveyed that the complex problems of multidisciplinary work transcend any particular discipline, similar to the description above in which the work as a whole ignores the boundaries of traditional disciplinary structure. As conveyed by one faculty member, multidisciplinary work:

> Uses…methods and ways of thinking that come from various fields to address questions that go beyond what is traditionally considered appropriate for any one field.

Type of product. Participants' expressions of the types of products that result from this multidisciplinary work echo their thoughts from other categories—that products of multidisciplinary research can be understood by multiple disciplines, are valued by multiple disciplines, or extend beyond the traditional disciplines that join to create it. A student entering the second summer of the program described multidisciplinary research in terms of general activity and desired result, including not only an integrative research product, but also the researcher's cognitive ability:

> Multidisciplinary is not only the research focusing on more than one discipline, but also the ability to see things from different disciplines' perspectives and concerns, and integrating one's research into a product that these disciplines can read and understand the significance of. Multidisciplinary research should encompass and connect different disciplines.

Although this student didn't make clear whether the researcher's abilities necessarily precede the research or develop en route, the last set of findings in this paper explores how this program's students consider similar issues.

Multidisciplinary vs. Interdisciplinary. Some survey questions asked participants to consider how multidisciplinary and interdisciplinary might be different in their minds and experience. Although some participants, usually faculty, said that they simply use "interdisciplinary" and "multidisciplinary" interchangeably, many respondents—both faculty and students—articulated differences in their understanding of the terms. Although the resulting data reinforced themes similar to those contemplated for multidisciplinarity alone, the juxtapositions revealed unexpected interpretations, rich comparisons, and sometimes obviously preliminary musings on the part of participants.

Several participants distinguished differences between inter- and multidisciplinary work based on whether the work was conducted independently or in collaboration with others. These faculty reflect a range of views similar to those presented by students:

> Interdisciplinary implies more integration and true collaboration than does multidisciplinary.
>
> I carry out interdisciplinary work by myself, e.g., a project that combines molecular biology, biochemistry, and physiology. If I were to expand the project to include atmospheric science, then the work would become multidisciplinary and I would need collaborators.

Perhaps even more significantly, interdisciplinary and multidisciplinary work appeared often distinguished by the relationships among the disciplines involved and in the ultimate uses and forms of those disciplines. For example, this student asserted that interdisciplinary work is comprised of fields that are related more so than with multidisciplinary work:

> Interdisciplinary conjures images of only two disciplines that are not necessarily very different from one another, whereas multidisciplinary seems to encompass more, vastly different areas.

Extending the themes of relatedness, many comments revealed a concern for the degree of integration—in most cases, a conviction that interdisciplinary work implies integration of parts into a whole or multiple disciplinary pieces into a new entity. As these students contemplated:

> I think my project may be more multidisciplinary than interdisciplinary, but I'm not sure. There are definitely interdisciplinary elements—like trying to understand the interaction of vegetation with atmospherically-deposited trace metals. I think the scale of my research—forest or watershed—and the system I've defined—air, water, soil, vegetation—make it impossible to capture the research in a single discipline. The techniques of multiple disciplines are required, but I'm interested in the system as a whole, and I think that, therefore, is interdisciplinary.

> Interdisciplinary, to me, is when a new field is created at the nexus of two already existing fields. For example, biophysics is a new 'interdiscipline,' but has its own technical language and culture, separate from biology and physics.

Multidisciplinary work was often distinguished as piecemeal, non-integrative, or merely applying parts of different disciplines to an endeavor without necessarily causing them to interact in any significant way. As one student simply stated:

> Interdisciplinary work is work at the intersection of two or more disciplines. You can have a multidisciplinary project with people from many different disciplines each doing his/her own thing and little cross-communication occurring. Interdisciplinary work really involves thinking across disciplines.

At first glance, the question of defining terms may appear semantic and inconsequential. The conceptions that researchers—new and veteran—held do not necessarily appear to affect their ongoing work, and these individuals continue to pursue the problems that interest them, with methods that suit each circumstance. These terms and conceptions do, however, affect individuals' views of project goals and assessments of success. For example, when asked how they would describe the program's goals regarding multidisciplinarity, some individuals were critical, while others were positive, largely based on the particular interpretations of "multidisciplinarity" and the program's efforts. From participating faculty:

> I think [the program] is truly multidisciplinary. [The program] creates teams of scientists from very different fields to collaborate on truly unique multidisciplinary projects.

> Both in conception and practice (seminars, discussions, research projects), [the program] has attempted to be <u>inter</u>disciplinary. But this is difficult to achieve.

From a participating student:

> [The program] has the noble goal of trying to create a multidiscipline. However, this is a very lofty goal and I wonder if it should be creating an interdiscipline. I say this because fundamentally some topics fit better than others...

Obviously, the definition of "multidisciplinarity"—and "interdisciplinarity"—is crucial to interpreting the exact assumptions that underlie these statements. Interesting is the emergence of consistent thematic elements that are seen to comprise this work that involves multiple disciplines, despite a lack of clear consensus about what such work should look like or how to denote it.

From a programmatic perspective, this exploration demonstrates a need for explicit discussions about research that draws upon multiple disciplines. What are the meanings that the program community can agree to share? What are the intended meanings embedded within the program goals? What expectations do we hold about how those meanings will be expressed in program outcomes and students' research? The range of answers may be generous and wide, enabling many students and faculty to envision themselves a part of the project community.

<u>Achieving Multidisciplinarity</u>

Regardless of the ultimate definition and image participants have in their minds of multidisciplinary science, some assumptions appear consistent: that multiple disciplines will be combined, that the research problem will be complex, that decisions will need to be made about extent of integration and interaction with other fields. Beyond the explicit use of the term and the potentially artificial explication of one's understanding of it lies the actual experience of becoming multidisciplinary. Students' discussions of their experiences in the program reveal three essential themes related to the learning and doing that progresses them toward demonstrating their increasing competence in conducting multidisciplinary science—understanding disciplines outside one's own, expanded consciousness, and interpersonal interaction. Faculty largely contribute two more—active engagement with disciplines outside one's own discipline, and independent multidisciplinary contributions to the scientific endeavor, briefly discussed here. (See Table 2.)

Understanding disciplines outside one's own. All students enter the program with at least undergraduate training in a science discipline, usually a traditional discipline such as biology or chemistry. Some students have begun graduate study, usually in a discipline related to their undergraduate emphasis. A few students have experience in fields that might be perceived as interdisciplinary already, such as geology or atmospheric science. Few, if any, students however, have educational or professional backgrounds that combine biospheric and atmospheric sciences, particularly to the extent that the program expects. Students' discussions of their experiences reveal how keenly they feel the need to get their footing in one or the "other" discipline.[1] As this student noted at the beginning of Summer 2:

> I have learned quite a bit about atmospheric topics but I do not feel I could effectively include them into my research. I have a hard enough time just worrying about the biology.

Indeed, students' self-perceptions of progress and ability to conduct research at the interface of biosphere-atmosphere domains emphasized their desire to master disciplinary content. Often they discuss their learning in terms of general knowledge, concepts, and technical know-how, but they also extend their assessments of their learning to account for recognizing differences in disciplinary cultures, language learning, and familiarity with the research efforts and underlying motivations of the researchers in the other discipline.

For example, a participating student at the end of the second summer noted recognition of different disciplinary cultures—different orientations to observation and the importance of hypothesis-testing—as evidence of being better able to work with both biology and atmospheric science. Several students cited learning the language of the other discipline as crucial to their advancement. Upon beginning the second summer, one student claimed:

> Multidisciplinary work involves using two (or more) disciplines to solve a problem pertinent to both. In order to do this, people from various fields have to be able to talk to each other or at the least, translate into each other's technical language.

Although the program organizes a system of educational workshops and seminars that focus on the content of the various domains, sheer exposure was discussed as a vital mechanism. Some students acknowledged that the program explicitly validated their pursuit of a discipline outside their own departmental training and contributed the freedom and access needed to become acquainted with another field so thoroughly.

Throughout the evaluation activities, students discussed the understanding of the core elements of the other discipline—the content of the field—both as essential to their progress to becoming multidisciplinary scientists as well as evidence of their advancement in the right direction. They discussed it as both a precursor as well as an outcome, implying that perhaps they find at least a bit of knowledge necessary for other types of learning and advancements. This seems plausible given the other two major themes that emerge from the student data—expanded consciousness and interpersonal interaction.

<u>Expanded consciousness.</u> Emerging from students' discussions of their learning was the development of an expanded consciousness. This consciousness appears most prominently as 1.) an increased awareness of the other discipline and 2.) an enhanced ability or inclination to adopt the perspective of a researcher in the other discipline. Most of these reports of this type of cognitive development appeared in the second year of the program.

In reporting greater consciousness of the other discipline, students noted seeing the other discipline's potential effect on their research, of appreciating the effect of its research contributions to their work, of acknowledging its presence embedded within a multifaceted research question. As one first-year student reported after increased exposure to biology, when you finally know specific trees, you don't see the forest any longer—you see individual trees and their

Table 2: Features of Multidisciplinary Competence

Theme: Understanding disciplines outside one's own (Content)

Emerging examples:
Increased content knowledge of other discipline(s)
Familiarity with research efforts in other discipline(s)
Recognizing cultural differences between disciplines
Learning the language of other discipline(s)
Increased familiarity with other discipline through exposure
Understanding connections between disciplines

Theme: Expanded consciousness (Consciousness)

Emerging examples:
Experiencing feelings of transcending one's own discipline
Perspective-taking
Adopting an identity and philosophy as a scientist
Acknowledging perceptions of self-confidence

Theme: Interpersonal interaction (Colleagues)

Emerging examples:
Generally talking to other people
Social/informal interactions
Discussing disciplinary content issues
Discussing research issues
Collaborating in research

Theme: Active engagement with disciplines outside one's own discipline

Emerging examples:
Learning by doing
Interacting with the scholarly literature
Posing research questions that consider other discipline(s)

Theme: Independent multidisciplinary contributions to the scientific endeavor

Emerging examples:
Student's development of own research career
Student's generation of novel ideas
Frustration with devaluation of multidisciplinary work within disciplines

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impact on the whole. Similarly, another student stated at the end of the first summer, "I actually think about it now...about trees and the environment, biosphere, when doing sampling."

After at least a summer in the program, several students reported feeling the omnipresence of the other discipline, a greater affinity for the other discipline, or an internal voice that reminded them of its existence. Most blatantly, one student finished the first summer claiming, "Now seriously, there's a little voice: 'How would the atmosphere affect that?'" I separate this notion of consciousness from that of perspective-taking because consciousness appears to be a largely passive activity on the part of students. Their integration of new learning with old is complete enough such that they conduct their research and are suddenly aware that the new discipline is there.

Students also discussed many versions of what I call perspective-taking, gaining fluency in adopting particular viewpoints that might not have previously occurred to them. Students sometimes discussed applying a series of perspectives to a problem, drawing on their knowledge of a new discipline's theories and methodologies. At other times, students described a global perspective that is somehow new and emergent, such that their entire mindset appeared transformed. Similarly, several students defined a multidisciplinary perspective as a way of thinking that incorporates an entire system of concerns, implying that to be multidisciplinary is to adopt a mentality that engages multiple perspectives in an ongoing fashion. An entering student provided an example that also exemplifies the potential difficulties of multiple conceptions:

> I think that multidisciplinary is a mindset, or taking a more general view. Interdisciplinary is a practice—you actually take elements from multiple disciplines and use them.

Active engagement and scientific contributions. Despite their lack of complete confidence in applying new knowledge and emphasis on internal processing, students deemed engagement with the activity and people of the other discipline and their own both crucial to learning and evidence of learning. Students most often reported that learning by doing was valuable. They expressed benefits from exploring other researcher's field sites, even informally, and from incorporating new aspects into their own research projects and presenting their own findings. Likewise, numerous comments surfaced about engagement with the scholarly literature of the other discipline, both as a tool to advance multidisciplinary skills as well as evidence of advancement. Students felt they had made progress when they could read material about the new discipline with greater understanding and fluency.

Faculty, on the other hand, focused less on the internal—and to them perhaps invisible—cognitive processes and more on tangible evidence. Faculty reported that they would know when they or their students had achieved multidisciplinary competence when they cited literature from outside the discipline, were cited by such literature, or produced co-authored papers with researchers from outside the field.

Interpersonal interaction. Related to engagement, but distinct and common enough to warrant its own thematic category, is interpersonal interaction—or the interaction between students and their colleagues, whether peers, faculty, or others engaged in science research. Similar to some other thematic categories, interpersonal interaction surfaced both in discussions of factors that facilitated multidisciplinary learning as well as of evidence of multidisciplinary learning. Students reported all types of interaction as valuable to their learning: formal and informal/social, discussions of technical questions and content specifics, brainstorming, and collaborative work.

Whereas the benefits of research collaborations were the most common references among faculty reports of interpersonal interactions related to multidisciplinary work, students most often mentioned general conversation. Interpersonal interaction, especially in the form of simple conversation, appeared to correspond with all three previously discussed thematic categories. Interactions with knowledgeable others served an instrumental role for the students, assisting them in learning the subject matter of the other disciplines. They also served to illuminate for students the thought patterns, problem solving techniques, and perspectives of other researchers, especially those with different disciplinary training. Finally, whereas faculty articulate a desire to witness more explicit forms of engagement with the new discipline, students value their newfound abilities to engage other researchers in conversation, to ask intelligent questions, and to integrate the answers and new ideas into their evolving work. In students' voices:

> Question: What things have advanced your ability to think about and to conduct research on biosphere-atmosphere interactions?
>
> Student response: My interactions here at the biostation: learning about other people's research, talking to different people about my research and

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during the academic year; brainstorming with my mentors, who give me different and highly relevant perspectives on the same system.

Student response: The permission (from my advisor) to formally spend time studying [another discipline] so that I may better understand the biosphere-atmosphere interactions. I also have enjoyed spending more time (both socially and intellectually) with my biosphere mentors, and this has helped me feel more comfortable with asking questions related to my research.

This last group of findings—students' perceptions of their steps toward multidisciplinary competence—illuminates the seemingly simple yet undeniable importance of program design issues, our starting point. Whereas program scheduling might seem at first glance a mere administration of a workshop series, the impact of the schedule appears to have affected students' progress. Acquiring content knowledge and exposure led to the familiarity and confidence to enter into new communities of scholars and to consider their research anew. Both cohorts described similar gains—assimilation of large amounts of complex new knowledge, the recognition of developing cognitions and awarenesses, social and formal interactions with knowledgeable others who assist in building confidence and modeling behavior, and application of these things to students' individual work. Whereas Cohort 1 described these things more clearly in the second year in the program, Cohort 2 described similar experiences at the end of the first summer and appeared to adapt to the program and competing demands of instruction and research more readily.

Discussion

Students' perceptions of factors that evince their progress toward competence in conducting multidisciplinary research are highly illuminating for this program. As Lattuca (2001) has suggested that processes, contexts and outcomes must be considered in order to understand interdisciplinarity more fully, the immediate needs of teachers and apprenticing researchers will benefit from a clearer understanding of the processes that may be at work in the context of this program. This understanding would promote better identification of the program's strengths and weaknesses.

Interestingly, students in the program appear to describe the same clusters of items as both evidence of and necessary contributors to their learning. This implies a cyclic process or perhaps a spiral or stepwise progression, where students must gain a critical mass of learning about subject matter, fluency in disciplinary languages, and confidence in interacting broadly before demonstrating significant progress. Thereafter, the cognitive map on which new knowledge can be located and the social network from which new insights and advice are derived appear to provide ongoing catalysts to research productivity. These speculations should drive further exploration of the relationships between the emergent themes of student progress toward multidisciplinary science--students' acquisition of content knowledge, enhanced consciousness, and a community of colleagues. Can a sequence or model of optimal experiences be derived?

Currently, if measured only in terms of tangible research outcomes, students' progress may be viewed very differently by program personnel, faculty, and the students themselves. Likewise, students' challenges may be invisible if they lie embedded within the largely internal processes of learning new content and adopting new viewpoints—if, for example, students become overwhelmed by the content of the new discipline, if they get bogged down in the multiple perspectives they try on for size, if they feel inadequate in conversations with colleagues from other disciplines and therefore fail to seek advice. Program goals that take into account more fully students' interim gains, perhaps not fully manifested in tangible products early on, could not only enhance the accurate assessment of student learning and program successes, but also encourage links to students' progress toward clearer demonstrations of their advancement toward conducting multidisciplinary science. These clearer demonstrations—such as evolving thesis research, presenting data at conferences, and proposing papers—appear advocated by faculty and undoubtedly remain the traditional indicators of progress in students' home departments. In this case, however, students must learn to configure each of these demonstrations as multidisciplinary, the new task with few models.

The lack of clear models of multidisciplinary research is reinforced by the multiple interpretations of multidisciplinarity that emerged from this program evaluation. The examples of faculty interpretations are intended to illuminate the range of definitions used across the generations of researchers. Adding complexity, program personnel and the messages of the program, mentor faculty at home departments, and students and their peers all interact to produce dynamic terms used to define work that incorporates, crosses, or somehow involves multiple disciplines.

Numerous scholars have studied the disciplines, their structures, their cultures, and their boundaries (Becher, 1989; Lattuca & Stark, 1994; Dressel &

Marcus, 1982; Biglan, 1973). A few have even studied interdisciplinarity and its variants, often deriving clearer categorizations of these types of activities (Klein, 1990; Klein & Newell, 1997; Lattuca, 2001; Miller, 1982). Despite the array of definitions for "multidisciplinary" that have emerged from this program evaluation, the definitions used by program faculty and students appear to resemble Lattuca's (2001) synthetic interdisciplinarity--also variously called multidisciplinarity or instrumental or cross-disciplinarity--or transdisciplinarity. The former, according to Lattuca's work, is motivated by questions that lie at the intersection of disciplines or in the gaps between disciplines. Integration is often missing, and thus, some scholars have criticized the mode as less than a true deviation from disciplinary approaches (Miller, 1982; Newell, 1998). The latter, however, emphasizes the reconfiguration of links between disciplines, perhaps for the generation of a new system of thinking or merely for the pertinent application within a particular context.

Interestingly, as Lattuca (2001) demonstrates, multidisciplinarity is often defined as a type of interdisciplinarity, granting some justification to the program participants who use multiple terms interchangeably. Also, however, Lattuca acknowledges critics who argue that some forms of interdisciplinarity are merely disciplinary in disguise (Miller, 1982; Newell, 1998). From a programmatic perspective, therefore, this program might serve itself well by using former conceptions and perhaps internal discussion to assert its collective definition--or definitions--of multidisciplinarity and the benefits it holds both for new researchers as well as the science community addressing crucial biosphere-atmosphere interactions.

Limitations And Next Steps

Given the number of variables in students' backgrounds, graduate school circumstances, and relationships with faculty, the differences within and between cohorts might also be attributed to factors beyond the scope of this discussion. For example, an analysis of differences in mentoring may reveal that students with ongoing, consistent faculty interaction display different experiences or adapt to the program's expectations more quickly. Such analysis is advisable in both the ongoing work of this program evaluation as well as in other multidisciplinary contexts.

Given the small sample of students and faculty involved in the program, continued evaluation of other student cohorts and consideration of a range of influencing factors is vital. Although the small sample helps amplify our understanding of individual experience and the myriad factors that might affect an unspecified process, isolating key variables that affect a majority of participants remains tenuous. Continued program evaluation and continuous program improvement will provide ongoing insight, perhaps in combination with similar work done on similar programs.

There is also some correlation in these evaluation findings between the program's construction and the themes emanating from students' discussions. This may indicate that students' conceptions of multidisciplinary science have not only been informed by, but also bounded by their expectations and experiences in the program. For example, students' emphasis on understanding disciplines outside their own parallels the heavy programmatic emphasis on educational workshops in the first summer. Likewise, the program's goal of facilitating a multidisciplinary community parallels the students' value of

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interpersonal interaction. Whether the program's structure predisposes the outcomes or whether the program design matches the needs of the educational process—or both—is difficult to discern. Nonetheless, in this context, the elements appear to foster each other and generate progress toward new competencies within a new generation of scientists.

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Footnotes

[1] I will refer to the "other discipline" as the science domain that is foreign to any particular student, assuming that each student has one of the domains as an area of expertise and one as an area of little experience. For students versed in biology, atmospheric science would be the other discipline, for example.

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